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ULTRASONIC FLOW SENSOR HAVING INTERLAID TRANSMITTING AND RECEIVING ELEMENTS

Technical Area

The air throughput in the intake and/or supercharge system of an internal combustion engine is measured using flow meters. Since the chemical process of combustion depends on the fuel to air mass ratio, the air mass throughput in the intake / supercharge system of the engine is to be measured, for which volume or back-pressure measuring methods are also being used. The maximum air mass flow to be measured is in the range between 400 kg and 1200 kg per hour, depending on the engine power. Due to the low idling consumption of today's internal combustion engines, the ratio from minimum to maximum air throughput is between 1:90 and 1:100.

Background Information

The Bosch Automotive Handbook / Bosch 23rd updated and expanded edition, Braunschweig; Wiesbaden, Vieweg, 1999, ISBN 3-528-03876-4 page 115 describes an ultrasonic flow measuring system. This system allows the propagation time t of an acoustic pulse as it travels through a medium to be measured (e.g., air) at an angle of inclination α. One measurement is taken upstream and one downstream using the same measuring path l. The resulting transit time differential is proportional to the volumetric flow rate.

In this document, see page 115, right-hand column, figure, a flow channel is described in whose walls two sensors facing one another are situated. The faces from which the acoustic pulses are emitted face one another.

Furthermore, ultrasonic flow sensors are known from the related art, which use the beam drift effect within a flowing medium for measuring the flow velocity. Furthermore, ultrasonic transducers manufactured using micromechanical or film technology are known from the related art.

Description of the Invention

According to the present invention, an alternating arrangement of an ultrasonic transducer is proposed, which operates alternatingly as transmitter and receiver antennas in such a way that all emitted individual sonic waves interfere to form common wave fronts. The most striking advantage of the alternating arrangement is the interlaid transmitting and receiving areas achieving uniform coverage. Transmission and reception characteristics that are symmetrical to one another are thus achieved in combination with a single ultrasound reflection within a flow channel. The functional division of the ultrasonic transducer into transmitting and receiving elements makes it possible to effectively separate weak transmitted signals from strong received signals, whose amplitudes may differ by several orders of magnitude. The symmetry between transmission and reception allows for direct ultrasound back reflections on a surface that is symmetrical to the transducer array without phase shifts being required between the individual transducer elements in transmitting.

The transducer array provided according to the present invention may be manufactured, for example, from a silicon substrate having micromechanically produced separating trenches between the individual transducer elements for mutual isolation. Strip-shaped electrodes, over which a PVDF (polyvinylidene fluoride) film is applied as a thickness-mode transducer, are applied to the silicon substrate. The film is provided on its top with a flat counterelectrode and a seal for mechanical protection. The transmitting elements of the ultrasonic transducer according to the present invention are in direct electrical contact with one another outside the transducer array and are connected to an oscillator. This enables the transmitter elements to emit in-phase ultrasonic waves. The individual waves interfere to form common wave fronts, which in first approximation are flat and therefore propagate across the flowing medium. The opposite wall of the flow tube is curved with a radius of curvature which is preferably equal to twice the diameter of the tube through which the medium flows. Due to this arrangement, the ultrasonic waves are collimated at the site of the transducer array to an approximately linear focus, whose position is a linear function of the velocity of the flowing medium and provides the volumetric flow rate. Since no ideal linear focus is obtained, the receiving element is determined at the highest received intensity. This is accomplished with the aid of a comparator and a sample-&-hold amplifier, which may be both implemented as operational amplifiers.

Drawing

The present invention is elucidated in more detail with reference to the drawing.

Figure 1	shows an interlaid transmitting and receiving transducer array situated opposite a curved reflection surface;
Figure 1.1	shows a design variant of an analyzer circuit;
Figure 2	shows a possible arrangement of the transducer array within the flow tube, the radius of curvature of the reflection surface being equal to twice the tube diameter;
Figure 3	shows the design of a flow-accelerating tube constriction formed by the arrangement of the transducer array;
Figure 4	shows a section through a transducer substrate on which the transducer array is formed;
Figure 5	shows interfering ultrasonic waves, and
Figure 6	shows a possible configuration of interfering wave fronts which cooperate with a curved reflection surface.

Description of the Exemplary Embodiments

An interlaid transducer array depicted in Figure 1 is part of an ultrasonic flow sensor 1. The depicted interlaid transducer array is preferably manufactured from a silicon substrate. Individual transducer elements 4 of interlaid transducer array 2 are decoupled from one another by separating trenches 3. Separating trenches 3 are produced micromechanically. There are strip-shaped electrodes on the silicon substrate (see Figure 4, item 11) representing interlaid transducer array 2. Strip-shaped electrodes 5 are covered by a PVDF (polyvinylidene fluoride) film 6 which is used as a thickness-mode transducer. The top side of PVDF (polyvinylidene fluoride) film 6 is provided with a flat counterelectrode 7 and a seal 12 for mechanical protection. Seal 12 may be made of epoxy resin or silicone, while counterelectrode 7 is preferably made of gold or aluminum. Strip-shaped electrodes 5 may be made of aluminum, gold, or platinum, while the substrate for ultrasonic transducer array 2 is preferably a silicon substrate. In one design variant, which is not graphically represented,

shielding electrodes may be provided between the transmitting and receiving electrodes of ultrasonic transducer array 2, which allows both mechanical and electrical coupling. Silicon substrate 11, a strip-shaped electrode 5, an area of PVDF film 6, an area of counterelectrode 7, and, if present, also seal 12 applied to the latter belong to a transmitter element 10 (see Figure 4). An area extends to the region between two adjacent separating trenches 3.

In Figure 1, reference numeral 10 denotes the transmitting elements of interlaid transducer array 2.

All transmitting elements 10 are in direct electrical contact with one another outside interlaid transducer array 2. In addition, transmitting elements 10 are connected to an oscillator 26 to enable emission of in-phase ultrasonic waves.

As is furthermore apparent from Figure 1, interlaid transducer array 2 is oriented perpendicular to flow direction 14 of the flowing medium. Opposite interlaid transducer array 2, there is a curved reflection surface 13 (see also Figure 2).

The transmitted signal is denoted by reference numeral 15, while the received signal is identified by reference numeral 16. In-phase ultrasonic waves 27 emitted by transmitting elements 10 of interlaid transducer array 2 interfere to form common wave fronts 28. Interference phenomena depend on the shape and variation of the ultrasonic waves due to deflection of molecules in air.

Individual ultrasonic waves 27 interfering to form wave fronts 28 are, in first approximation, flat and therefore propagate transversely to flow direction 14 of the medium. Propagating common wave fronts 28 strike an opposite wall of a flow tube 17, which has a radius of curvature 19. Radius of curvature 19 is preferably equal to twice the tube diameter 20 of flow tube 17 ($r = 2d$). Due to curvature 23 of reflection surface 13, propagating wave fronts 28 are collimated to a linear focus 29 at the location of interlaid transducer array 2. Position 30 of linear focus 29 is a linear function of the velocity of the medium flowing in flow direction 14. Due to the linear relationship between the flow velocity of the flowing medium and position 30 of linear focus 29, the volumetric flow rate of the flowing medium passing by interlaid transducer array 2 may be inferred. Since usually no ideal linear focus 29 is established, the receiving element having the highest received intensity of the ultrasound signal is ascertained. Figure 1 shows a first linear focus 29 at point X_0, which is established without a flowing medium. First linear focus 29.1 is shifted along the X axis to the point denoted by

reference numeral 29.2 (see position x_1 on the X axis). The deflection of the linear focus from position 29.1 to 29.2 is caused by the deflection due to the medium flowing in flow direction 14. Reference numeral 28 denotes the interfering wave fronts propagating in the direction of a curved reflection surface 13.

Figure 1.1 schematically shows an analyzer circuit. The analyzer circuit according to Figure 1.1 includes a signal multiplexer 34, which is connected to interlaid transducer array 2. A signal processor 36 and a comparator 31 are connected downstream from signal-multiplexer 34. The receiver element having the highest received ultrasound intensity may be determined with the aid of comparator 31 and a sample-and-hold amplifier 32, which may also be designed as an operational amplifier. Signal multiplexer 34 is activatable via a multiplexer control 35. U_1 denotes the input voltage signal which is picked up at interlaid transducer array 2; U_2 denotes the voltage signal at the output of sample-and-hold amplifier 32. Alternatively, the center of gravity of the intensity distribution which is established over all strip-shaped electrodes 5 of interlaid transducer array 2 of ultrasonic flow sensor 1 may also be ascertained.

Figure 2 depicts a cross section through a flow tube in which the interlaid ultrasonic transducer array according to the present invention is installed.

Flow tube 24 is delimited by a wall and has a diameter 18 (see d). Reflection surface 13 having a curvature 23 is integrated into the wall of flow tube 24. Radius of curvature 19 of reflection surface 13 is preferably twice the tube diameter 18. In Figure 2, interlaid transducer array 2 is integrated into a wall of flow tube 24. The medium whose flow rate, i.e., volumetric flow, is to be ascertained flows in the right to left flow direction 14 in Figure 2.

An auxiliary circle 17 has a radius approximately twice the diameter 18 of flow tube 24. Auxiliary circle 17 is used for indicating the curvature of curved reflection surface 13. Figure 2 shows differing wave fronts 28 emitted by interlaid transducer array 2 and moving toward curved reflection surface 13 formed in curvature 23, and wave fronts 28 reflected by the reflection surface to the receiving elements of interlaid transducer array 2.

Figure 3 shows a design variant of an interlaid transducer array having a flow-accelerating tube constriction.

As is apparent from Figure 3, interlaid transducer array 2 is installed in a surface of the tube wall of flow tube 24, which is formed in a curvature 23. Curvature 23 forms a surface depression within the tube wall of flow tube 24, so that the flow cross section between bottom 9 of interlaid transducer array 2 and the top of reflection surface 13 is constricted, which is indicated by distance 25 d_1, which is smaller than distance 18 d shown in Figure 2 between flow tube 24 and the top of integrated reflection surface 13 integrated into the wall. In the design variant illustrated in Figure 3, the cross section of flow tube 24 is constricted, so that the curvature cross section below interlaid transducer array 2 is narrowed overall and the flow is accelerated in flow direction 14. This makes it possible to effectively suppress the deposition of particles such as dust or the like on the inside of the wall of flow tube 24 and on bottom 9 of interlaid transducer array 2.

This makes forming a curvature in reflection surface 13 for beam collimation unnecessary if the individual transducer elements of the ultrasonic flow sensor are excited with a phase delay in such a way that the path difference between the individual ultrasonic waves 27 results in a curved or flat wave front 28 (see Figures 5 and 6). If these wave fronts 28 have a radius of curvature which is twice the tube diameter immediately after their emission, the waves converge after reflection on the opposite wall into a linear focus 29 at the point of interlaid transducer array 2.

The determination of the receiving element having the highest intensity was described previously. Instead, a center of gravity of the intensity distribution of the received signal may also be determined, thus improving the measurement resolution. In general, reflection curvature 13 results in a cross-section widening and thus in a local reduction of the medium's flow velocity in flow direction 14 in flow tube 24. This may result in some cases in increased deposition of particles such as dust. Deposition of dust and other particles entrained in the flowing medium may be suppressed by the design variant depicted in Figure 3. The interlaid transducer array 2 proposed according to the present invention makes an alternating arrangement of ultrasonic transducers possible which alternatingly act as transmitting and receiving antennas in such a way that all emitted individual sound waves 27 may interfere to form common ultrasonic wave fronts 28.

The advantage of the proposed alternating arrangement is the interlaid transmitting and receiving areas of uniform coverage whereby, in combination with a single ultrasound reflection within flow tube 24, a symmetric transmitting and receiving system may be

achieved. The functional division into transmitting and receiving elements advantageously allows separating the weak transmitted signals from the strong received signals whose amplitudes may differ by several orders of magnitude. Symmetry regarding transmission and reception makes direct ultrasound reflection on a surface oriented symmetrically to the ultrasonic transducer array possible without requiring a phase shift between the individual transducer elements.

Figure 4 shows a cross section through a transducer element 4. Individual separating trenches 3 are formed in silicon substrate 11. Strip-shaped electrodes 5, over [which] PVDF film 6 is applied, are located on the top of silicon substrate 11. Flat counterelectrode 7, which is made of a metallic material such as gold, aluminum, or platinum, for example, is above PVDF film 6. A seal 12 in the form of an epoxy resin protective layer may optionally be applied on the top of flat counterelectrode 7. Reference numeral 10 denotes the top of a transmitting element depicted as an example in Figure 4. Compared to the thickness of strip-shaped electrode 5 or flat counterelectrode 7, silicon substrate 11, which represents the carrier substrate, has a substantially greater thickness.

Figure 5 shows individual ultrasonic waves 27 emitted by transmitting elements 10, which, due to their mutual overlapping, combine to form an interfering wave front 28. In Figure 5, interfering wave front 28 which is formed runs essentially parallel. In contrast, the individual ultrasonic waves depicted in Figure 6 run as curved wave fronts 28 due to a phase shift for collimating without curved reflection surface 13.

List of Reference Numerals

1	ultrasonic flow sensor
2	interlaid transducer array
3	separating trench
4	transducer element
5	strip-shaped electrode
6	PVDF film
7	flat counterelectrode
8	top
9	bottom
10	transmitting element
11	silicon substrate
12	epoxy resin protective layer
13	reflection surface
14	flow direction
15	transmitted signal
16	received signal
17	auxiliary circle
18	array-reflection surface distance (d)
19	radius of curvature, reflection surface
20	tube diameter
21	tube constriction
22	curvature, reflection surface
23	curvature
24	flow pipe
25	d_1 (distance in flow constriction)
26	
27	individual ultrasonic wave
28	interfering wave fronts (curved or parallel)
29.1	first linear focus (without flow)
29.2	second linear focus (with flow)
30	
31	comparator

32 sample-and-hold amplifier

33

34 signal multiplexer

35 multiplexer control

36 analog signal processing